

EVALUATION OF THE TERMINAL AREA PRECISION SCHEDULING AND SPACING SYSTEM FOR PERFORMANCE-BASED NAVIGATION ARRIVALS

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Abstract

In 2012, NASA and FAA jointly conducted a human-in-the-loop air traffic simulation to evaluate the utility of the Terminal Area Precision Scheduling and Spacing (TAPSS) system for supporting Performance-Based Navigation arrival operations during periods of congestion at a mid-sized airport. The TAPSS system is a trajectory-based strategic planning and tactical control tool that was developed to efficiently manage arrivals. For this study, the TAPSS system was enhanced to handle Required Navigation Performance arrivals. A baseline case, where none of the TAPSS system's advisories were provided, was run along with two different configurations of the TAPSS system with differing sets of controller advisory tools. The engineering data indicate that the TAPSS system has a potential to enable efficient Performance-Based Navigation arrival operations. The participating controllers found the TAPSS system's advisories useful. When controllers were given the full set of TAPSS advisory tools, 90% of Required Navigation Performance arrivals stayed on-path as compared to 87% in the baseline case, the average extra track distance of Area Navigation arrivals decreased by 36%, and the average number of controller voice communications decreased by 13%.

Introduction

The growth of global demand for air transportation service has put increasing strain on the nations' air traffic management system. To relieve this strain, the International Civil Aviation Organization has urged all nations to adopt Performance-Based Navigation (PBN) [1], which can help to reduce air traffic congestion, decrease aviation fuel consumption, and protect the environment [2, 3, & 4]. In the European Community, increased use of PBN operations is a

part of the Single European Sky initiative [5]. This initiative is the roadmap to drive the community's air traffic management system modernization in connection with the Single European Sky ATM Research (SESAR) [6]. In the United States, the FAA has been introducing improved routing and navigational performance capabilities that enable the broader use of PBN operations as a part of the air traffic management optimization program, the Next Generation Air Transportation System (NextGen) [7 & 8].

Performance-Based Navigation has two components, Area Navigation (RNAV), and Required Navigation Performance (RNP). Aircraft equipped with RNAV are able to fly a direct navigation path between two locations, without passing directly over ground-based navigation aids. With RNP, aircraft are able to fly the RNAV path within a predetermined path-deviation threshold. Significant research and development has been conducted in the US and the EC to enable aircraft to simultaneously execute efficient descent and PBN operations, while working with arrival-scheduling tools like the FAA's Traffic Management Advisor (TMA) or the European Arrival Manager (AMAN) to maintain throughput [9 - 14]. As an extension of these efforts, NASA has developed a Terminal Area Precision Scheduling and Spacing (TAPSS) system that can support increased use of PBN operations during periods of high traffic demand, while supporting fuel-efficient, continuous descent approaches. In the original development of this system, arrival aircraft are assigned fuel-efficient RNAV Standard Terminal Arrival Routes before their initial descent from cruise, with routing defined to a specific runway. The system also determines precise schedules for these aircraft that facilitate continuous descent operations through the assigned routes. To meet these schedules, controllers are given a set of advisory tools to precisely control aircraft [15].

The TAPSS system has been evaluated in a series of human-in-the-loop (HITL) air traffic simulations during 2010 and 2011. Results indicated increased airport arrival throughput up to 10% over current operations, and maintained fuel-efficient aircraft decent profiles from the initial descent to landing with reduced controller workload [15, 16, & 17]. The TAPSS system was also found to be robust. It is viable with mixed RNAV routes, where some routes are defined to specific runways and others require controller instruction for transition to final approach, and has also been shown to support missed-approach operations [18 & 19]. Whereas the TAPSS system is designed to support PBN operations using either RNAV or RNP routes, the latter has not been tested with the system.

This paper focuses on results from a joint NASA and FAA HITL simulation conducted in 2012. In this simulation, the original TAPSS system was adapted to evaluate PBN arrival operations to a mid-sized airport within a constrained terminal area due to the close proximity of a major airport. To address this constraint, RNAV routes and RNP with the particular capability known as Radius-to-Fix (RNP-RF) approaches to a short final were used. Arrival segments from cruise to the boundary of the terminal area were not evaluated. The purpose of this simulation was to get feedback on how current operations could benefit with the TAPSS system and also to evaluate the efficacy of the advisory tools to support the broader use of PBN in the US National Airspace System. This paper presents a brief description of the TAPSS system and its adaptation for the simulation, followed by a description of the simulation evaluation. Results from the evaluation are discussed and the paper ends with some concluding remarks.

Terminal Area Precision Scheduling and Spacing System Software Description

The TAPSS system was configured to handle PBN arrival operations in the terminal area using two different sets of controller advisories. This section briefly describes the original system, enhancements made to support the research objectives, and the controller advisory tool sets.

TAPSS System Overview

The original TAPSS system is a trajectory-based strategic planning and tactical control tool that provides integrated arrival management between the Air Route Traffic Control Center (Center) and the runway. In this system, arrival aircraft are managed starting in Center airspace, approximately 200 nautical mile (NM) from the runway. These aircraft fly Vertical Navigation (VNAV) descents along the RNAV approaches to the runways, following any controller clearances in the Center and Terminal Radar Approach Control (TRACON) area.

The TAPSS system consists of two major capability groups. The first group contains trajectory prediction, constraint scheduling, and runway balancing capabilities that are built upon the existing Time Based Flow Management (TBFM) [9 & 20]. With these capabilities, the system performs high-fidelity modeling of four-dimensional aircraft trajectories from cruise to landing. With these trajectory models and constraints for radar separation at arrival merge points and wake-vortex separation, the system provides the arrival sequence, scheduled times of arrival (STA), balanced runway assignments, and necessary delays to meet the STAs at schedule points.

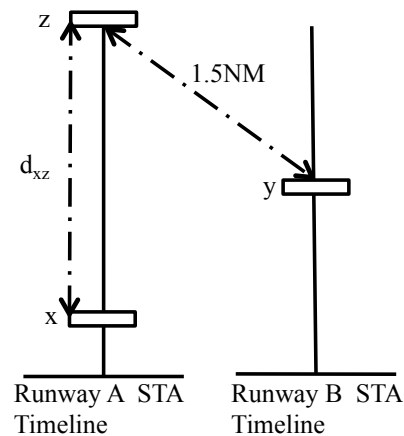
The second major capability group of the TAPSS system contains controller decision support advisory tools that are built upon the Efficient Descent Advisor (EDA) [10, 21, & 22], and the Controller Managed Spacing (CMS) technologies [23, 24, & 25]. In the Center, controllers are given the EDA based tool to provide speed and path-stretch advisories to meet the meter-fix STAs. In the TRACON, controllers are given timelines of estimated and scheduled times of arrival, runway assignments, and a set of CMS tools to provide speed advisories, early/late indicators, and trajectory slot marker advisories to meet STAs to meter points in the terminal area. The trajectory slot markers are advanced spatial and temporal delay visual cues that are generated for RNAV flights. On the controllers' display, the slot markers are rendered to follow the associated flights' RNAV route, meet all published speed and altitude restrictions, and arrive on time at the flights' STAs to the meter points.

TAPSS System Software Modifications and Enhancements

To support the research objectives of the joint NASA and FAA HITL simulation, a few modifications and enhancements were made to the original TAPSS system. Due to the FAA rollout of the advance terminal area PBN procedures at mid-sized airports first, the TAPSS system was modified to manage arrival aircraft as they entered the TRACON.

Next, a new capability was added to the system's precision scheduler to process parallel dependent runway approaches. These approaches require use of stagger-separation criteria for dependent finals [26]. Figure 1 illustrates the stagger-separation scheduling algorithm that was added to the TAPSS system. In this figure, the scheduled landing time is at the bottom of the timelines. This new capability was necessary as some of the mid-sized airports have runways with less than 2500 feet centerline separation, requiring parallel dependent approaches.

Next, the system was configured to process an additional type of aircraft with much slower speed than previously simulated jets and turboprops. This speed is often found with general aviation aircraft (e.g. Cessna 172) that operate at mid-sized airports. Finally, the TAPSS system was updated to provide the runway landing sequence number to controller displays. This number is computed from the runway STAs.



x is the last flight scheduled on runway A.
y is the last flight scheduled on runway B.

Following x and y, z has to be separated from x by the wake vortex separation d_{xz} .
 $STA1 = STA(x) + d_{xz} / \text{GROUND SPEED}(z)$;

z also has to be at least diagonally 1.5 NM away from y.
 $STA2 = STA(y) + f(1.5\text{nm}) / \text{GROUND SPEED}(z)$;

$f(1.5 \text{ NM})$ is a function that maps the diagonal 1.5 NM to a distance along runway A's approach, given runway A and B's respective location and heading.

$STA(z)$ is then the greater of $STA1$ and $STA2$.

TRACON Advisory Tool Sets

The TAPSS system's controller decision support advisory tools were configured to provide two levels of advisories, Limited Advisories and Full Advisories. The Limited Advisories reflected the existing but dormant capabilities of the current terminal automation equipment in the US. Simple numerical delay, landing sequence, and runway assignment information were provided on the controllers' flight data-block. The Full Advisories included all of the TRACON TAPSS advisories as discussed in the references, such as trajectory slot markers, and timelines rendered on the primary controllers' display. Table 1 lists the advisories included in the Limited Advisories and the Full Advisories set. Figure 2 shows an example of the advisories in the table, with an exception of the timelines.

Simulation Evaluation Description

PBN arrival operations using the TAPSS system was evaluated in a high fidelity HITL simulation. This three-day simulation was conducted in one of the Air Traffic Control laboratories at NASA Ames Research Center. This section describes the simulation environment, participants, RNAV and RNP approaches, simulation scenarios, and experimental test conditions.

Simulation Environment

The TAPSS system for PBN arrivals was evaluated using the Multi-Aircraft Control System

Figure 1. Illustration of stagger-separation schedule algorithm

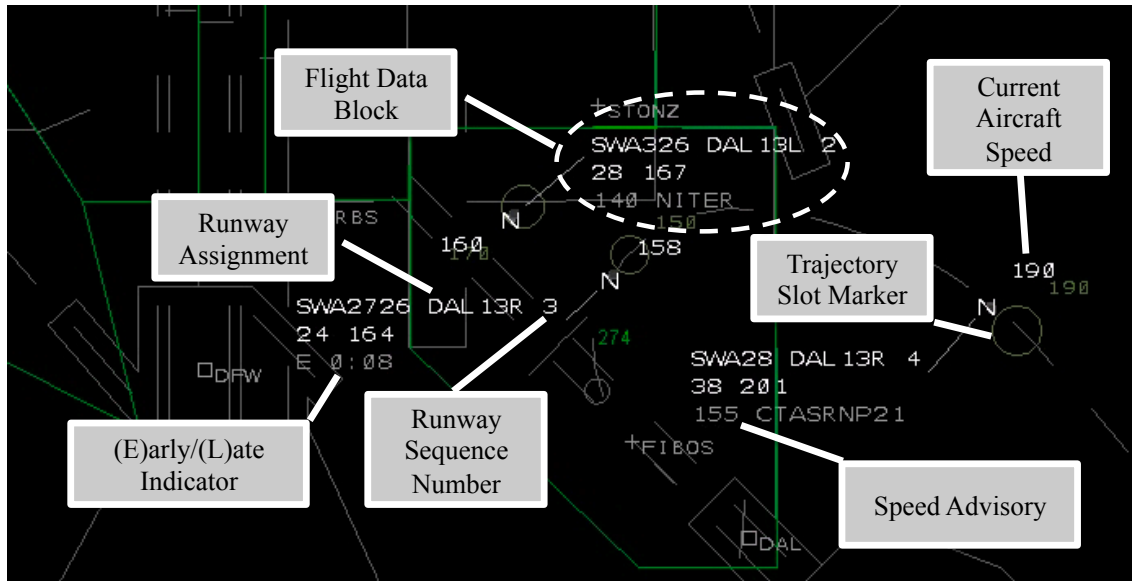


Figure 2. The TAPSS system controller advisories

(MACS). MACS provides high-fidelity display emulations for air traffic controllers and managers, as well as user interfaces and displays for confederate pilots, experiment managers, analysts, and observers. MACS also has flight deck capabilities that simulate current-day flight technologies that allow pilots to adhere to ATC clearances [27]. MACS was adapted to simulate arrivals into Dallas-Love Field airport (DAL) in the Southeast two-runway configuration landing on runways 13L and 13R. DAL is located in the Dallas-Ft Worth (D10) TRACON. Arrival operations were in Instrument Meteorological Conditions utilizing parallel dependent approaches. DAL was selected by the FAA as a representative mid-sized airport within a constrained TRACON airspace due to the close proximity of a major airport, in this case Dallas-Ft Worth International Airport (DFW), one of the busiest in the world.

With MACS, one of the Air Traffic Control simulation laboratories at NASA Ames was arranged with two feeder positions that handed off traffic to one final position. The feeder positions, which were designated as Feeder East and Feeder West, were located to the left and the right sides of the final position, which was designated as the Final. These positions were configured to closely emulate today's operation. The simulation focused on the ability and the performance of the TRACON controller team to

safely control traffic to the STAs at route merge-points and runways.

Table 1. TAPSS System Advisories

Limited	Full
Runway assignment	Runway assignment
Runway sequence number	Runway sequence number
Early/Late indicator	Early/Late indicator, or speed ¹
	Current aircraft airspeed
	Trajectory slot marker
	Timelines to scheduled points

Simulation Participants

Four FAA controllers participated. All participants were Full-Performance Level (FPL) terminal controllers and members of the National Air Traffic Controllers Association. Two of them had experience controlling traffic in the D10 TRACON and the other two were from New York and Southern California TRACONs. While the four controllers alternately covered the three positions, two feeders

¹ Early/Late indicator is displayed when a single speed advisory cannot be calculated.

and one final, the Final was always covered by the two with the D10 TRACON experiences. Since none of the participants were experienced with the TAPSS system, each position had a dedicated subject matter expert to support training, simulation operations, and answer questions about the technology. Handouts depicting DAL RNAV and RNP arrival routes were provided to help orient them to the airspace.

RNAV and RNP Approaches to DAL

The simulated RNAV approaches from five of the D10 TRACON meter-fixes to DAL were adopted from the Site Adaptation Requirements and Design document for Dallas-Ft Worth Air Route Traffic Control Center [28]. These routes generally follow the flow of existing traffic. In addition, two simulated RNP approaches were used, one per runway. These approaches were based on ones designed by GE Naverus corporation to meet the following requirements by the FAA: 1) shall not result in any new residences or noise-sensitive facilities being exposed to more than 65 dB day-night average sound level (DNL) aircraft noise, 2) shall not generate a 1.5 DNL increase in noise to any sensitive land uses, and 3) shall overfly existing historical VFR flight tracks.

Figure 3 shows a plan-view of the RNAV routes in solid lines and RNP routes in dashed lines. Also shown in circles are the meter-fixes, where the approaches are initiated, route merge-points (as cross hatches), runways 13L and 13R, and as a reference, DFW (illustrated as \|\|). The layout of these approaches reflects rigid airspace constraints due to a close proximity between DAL and DFW. For example, altitude constraints were applied to de-conflict the DAL approaches from the DFW arrivals. Spatial constraints were used as well, with keeping the DAL finals from not extending beyond one NM from STONZ to separate from the DFW finals. Since DAL is located toward the East side of the D10 TRACON, approaches from the Eastern meter-fixes, FINGR and YEAGR, are shorter in length than the Western ones. The waypoint FORMN (triangle) is shown as well. This was the last position where the Feeder East can issue the RNP clearance to runway.

Simulation Scenarios

The simulation traffic scenarios were prepared to closely resemble current day arrival operations at DAL. Feedback from the subject matter experts of the D10 TRACON helped refine the scenarios. The hourly DAL arrival rate was set to 40 for the nominal

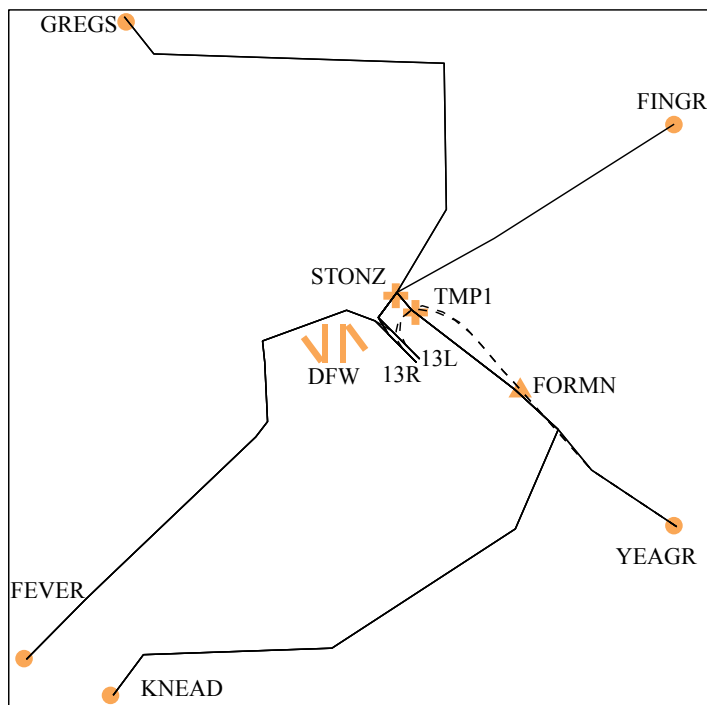


Figure 3. Simulation airspace with RNAV and RNP routes.

continuous traffic. The directional distribution of the DAL arrival traffic was set to 25% of the aircraft from the Northeast, 35% from the Southeast, 30% from the Southwest, and 10% from the Northwest. The distribution of aircraft type was 50% large jets, 25% regional jets, 20% turboprops, and 5% aircraft with speed much slower than turboprops. All traffic was assumed to be RNAV capable. In addition, a half of the large jets was assumed to be RNP capable. All RNP traffic was set to arrive from the Southeast using the short RNP-RF intercept to final.

Two aircraft demand scenarios were generated to create simulation runs of approximately 45 minutes in duration. Variation in these scenarios included arrival demand distribution and callsigns. That is, for the same traffic demand, the first scenario had 10% more arrivals during the first half of the simulation than the second scenario. In addition to the DAL traffic, arrivals and departures at four satellite airports in the D10 TRACON, Addison, Denton, McKinny, and DFW, were included in both scenarios to enhance reality of the simulation.

Experimental Test Conditions and Data Collection

For the experiment, arrivals from the YEAGR meter-fix, including all of the RNP capable ones, were assigned to the Feeder East. The Feeder West managed arrivals from the GREGS, FEVER, and KNEAD meter-fixes. Arrivals from the FINGR meter-fix were assigned to the Final. During the experiments, a traffic management supervisor verbally coordinated with the Final for the release of the satellite airport departures. The participants did not control the satellite arrivals.

Three test conditions were used: 1) Baseline condition, where none of the TAPSS system's advisories were provided, 2) Limited Advisories, as listed in Table 1 and 3) Full Advisories, as listed in Table 1. In the Baseline condition, the Final issued runway assignments for all arrivals. In the other two conditions, the Feeders assigned the arrival runways. The simulation did not incorporate wind conditions.

The number of data collection runs, ten in total, for the test conditions and demand scenarios are summarized in Table 2. The controllers were requested to follow the TAPSS system's advisories unless they felt separation was compromised. At that

point, they were allowed to use any technique to ensure separation. The collected data include aircraft state, such as latitude, longitude, altitude, and indicated airspeed, audio of controller-pilot communication, and video of the controllers' scope. Also, post-run controller questionnaires were collected to assess the TAPSS system.

Table 2. Number of Data Collection Runs for Test Condition and Air Traffic Demand Scenario

	Baseline	Limited Advisories	Full Advisories
Scenario 1	1	1	1
Scenario 2	2	2	3

Results and Discussion

The primary purpose of this simulation was to evaluate the TAPSS system's capability to support PBN operations in the TRACON, with a focus on RNP arrivals. Therefore the results and discussion in this section will compare and contrast the impact of the TAPSS system on RNP arrivals. In particular, path-conformance of RNP arrivals and controller voice communication task-load during RNP operations will be examined. In addition, the impact of the TAPSS system on the rest of RNAV arrivals will be examined. This section ends with the controller's assessment of the TAPSS system based on analyses of extensive participant questionnaires.

Impact of the TAPSS System on RNP Arrivals

During the ten data collection runs, there were 50 RNP arrivals, five in each run. Of the 50, 15 were in the Baseline condition, 15 in the Limited Advisories condition, and 20 in the Full Advisories condition. To evaluate the impact of the TAPSS system on these arrivals, path-conformance was tested using controller clearances. In this test, off-path was determined when a heading clearance was given after the RNP clearance. Figure 4 shows the result of this test. The trend in this figure shows that more RNP arrivals were on-path in the Full Advisories condition than in the Limited advisories condition, or in the Baseline condition. Figure 5 shows an example of an off-path flight. In this example, the Feeder East cleared a flight for RNP arrival. However, starting approximately 70 seconds after a hand-off of this flight, the Final issued a series

of heading clearances to avoid a conflict with another flight, taking the RNP flight off-path.

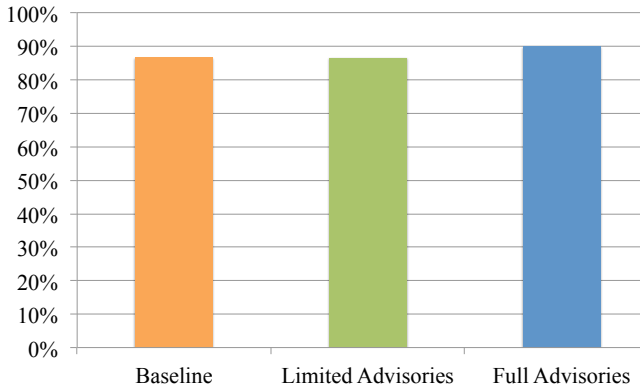


Figure 4. Percentage of on-path RNP arrivals

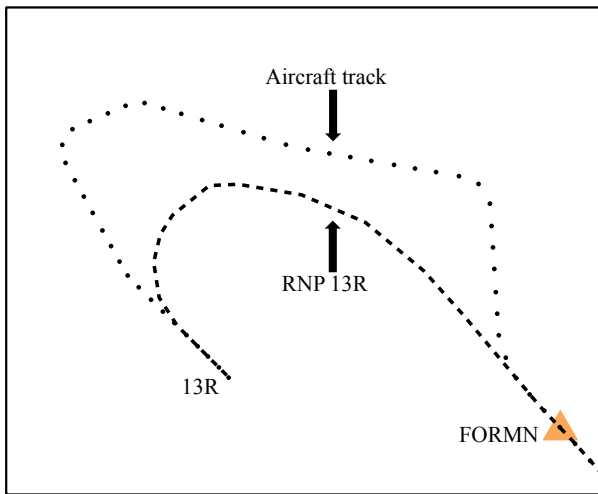


Figure 5. Example of off-path RNP arrival

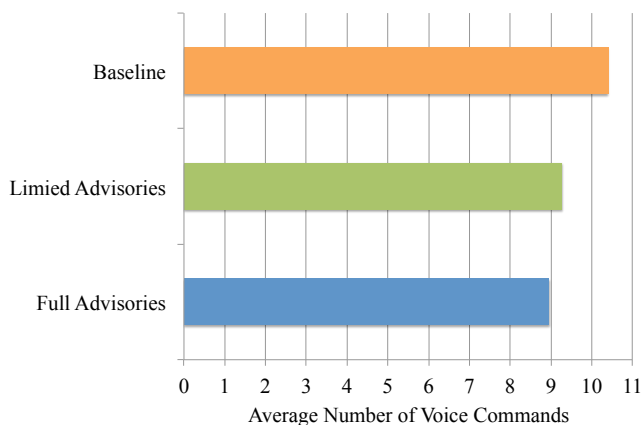


Figure 6. Average number of voice commands per RNP arrival

Following the path conformance analysis, the number of voice commands issued to RNP arrivals was examined to assess controllers' communication task-load per test condition. Figure 6 shows that compared to the Baseline condition, using TAPSS decreased the average number of voice command per RNP arrival by 10.9% in the Limited Advisories condition, and 13.9% in the Full Advisories condition. This and the path conformance results indicate that the TAPSS system has a potential to enable efficient RNP arrival operations while decreasing controller's communication task-load in a mixed RNP capability operation.

Impact of the TAPSS System on RNAV Arrivals

By design, 25% of the simulated DAL arrivals were RNP. The rest of arrivals were RNAV without RNP. To evaluate the impact of the test conditions on these RNAV arrivals, the extra track distance flown by them and the number of voice commands issued to them were examined. Extra track distance was defined as the distance flown outside of its RNAV path. A lateral off-path threshold of 1 NM was used in this definition. Figure 7 illustrates this extra track.

Figure 8 shows the average extra track distance flown per RNAV arrival for each test condition. Compared to the Baseline condition, RNAV arrivals flew on average 5.6% longer extra track distance in the Limited Advisories condition, and 36.8% shorter in the Full Advisories condition. Figure 9 shows the average number of voice commands issued per RNAV arrival for each test condition. Compared to the Baseline condition, the average number of voice commands per RNAV arrival increased by 4.9% in the Limited Advisories condition, and decreased by 12.4% in the Full Advisories condition.

Results shown in Figure 8 and Figure 9 indicate that use of the TAPSS system is beneficial in the Full Advisories condition, helping more RNAV arrivals to stay on their path with less communication task-load than in the Baseline condition. However, in the Limited Advisories condition, detrimental impacts are indicated. These contrasting results between the two conditions are perceived to be caused by the different controller techniques used in them.

In the Full Advisories condition, controllers were provided with numerical delay information and spatial visual cues via trajectory slot markers. With

the latter, controllers quickly translated the numerical delay information into a speed reduction, vectoring,

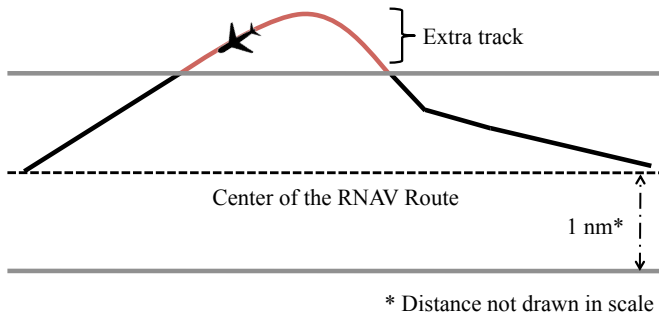


Figure 7. Illustration of an extra track

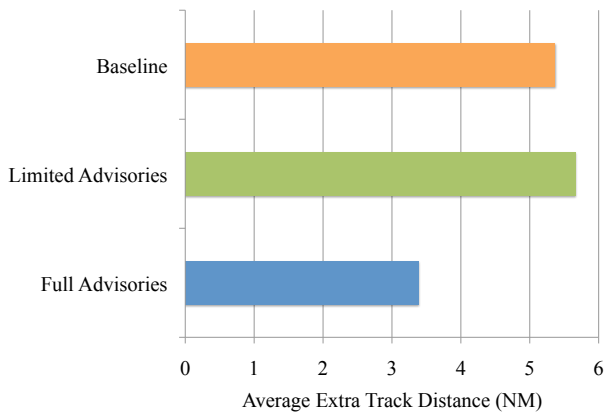


Figure 8. Average extra track distance per RNAV arrival

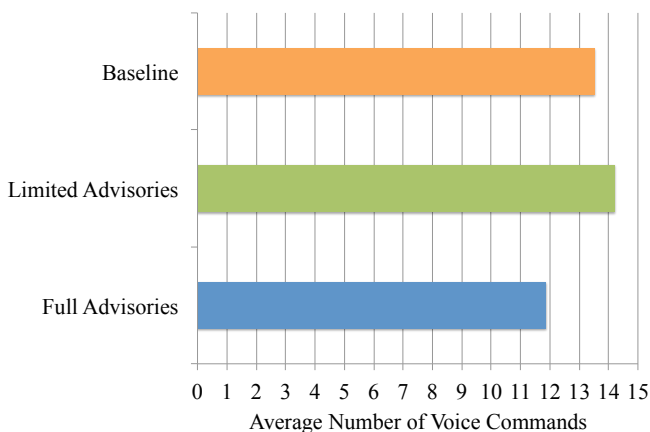


Figure 9. Average number of voice commands per RNAV arrival

minimizing the use of path vectoring later along the arrival path. In the Limited Advisories condition, controllers were provided with only the numerical delay information. Lack of the spatial visual cues is perceived to cause controllers to intervene later, which resulted in having to resort to path vectoring to absorb the necessary delay. This difference between early delay absorption vs. late delay absorption controller techniques can be observed from the two-dimensional aircraft tracks in Figs. 10 a) and b). Figure 10 c) shows the Baseline tracks for comparison with the other conditions, indicating the most late vectoring in this condition. Future simulations are anticipated to verify this perceived difference in controller techniques and accompanying results.

Controller's Assessment of the TAPSS System

The three on-position controllers completed a questionnaire after every run (3 x 10 = 30 questionnaires), and it is these responses that are collated in the following subsections.

There were three dependent variables of interest – primarily the availability of advisories, and other variables were the level of traffic and the controller position. An additional variable, determined during the study, was a learning effect from the first to the last run. This section focuses only on the differences and similarities between respondents' answers when sorted by the advisories available.

There were three test conditions – the Full Advisories where six advisories (the second column of Table 1) were available, the Limited Advisories with three available advisories (the first column of Table 1), and the Baseline where none of these advisories were available.

Subjective Workload

Workload data were collected in post-run questionnaires. In these, the participating controllers were asked to complete the six sub-scales that make up the NASA TLX [29]. They did not complete the weighting portion of the TLX, so the results reported are the sub-scales.

The participants used the full scale, 1-7 ("very low" to "very high"), for mental demand but only used between 1-5 for the physical demand, time pressure and frustration ratings, and between 4-7 ("moderate" to "very high") for success. Excluding

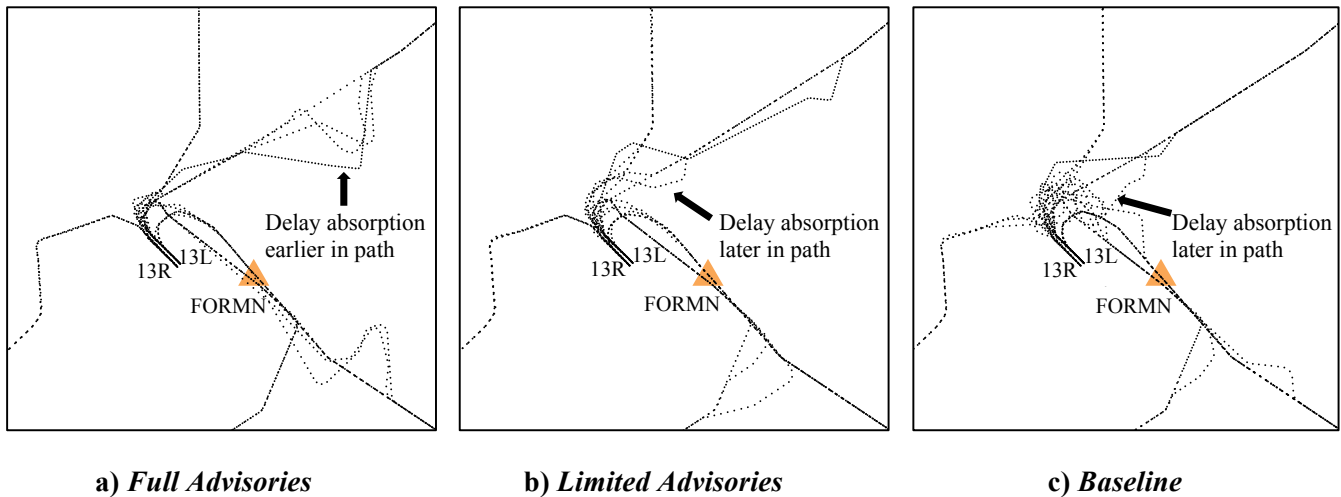


Figure 10. Two-dimensional aircraft tracks

the success sub-scale, the range of ratings used is generally good. The workload ratings were organized by the test condition and a mean was calculated for each sub-scale. Figure 11 shows the mean sub-scale ratings for the three test conditions over the six TLX sub-scales. As shown in Table 2, there were three data points per participant for the Baseline and the Limited Advisories conditions, and four data points per participant for the Full Advisories condition. The success ratings were reversed so that in all sub-scales a lower score is, broadly-speaking, more desirable.

The means indicate the participants thought they had “a comfortable level of” mental workload, time

pressure and physical load and put in “average” effort. They rated their frustration as “somewhat low”, and thought they were “somewhat successful” (possibly slightly underrating themselves as the objective results indicate general success). Although 7 in the scale was rarely used to describe workload, for mental demand it was selected once in the Full Advisories condition by the Final, who noted he had to reduce some aircraft to their final approach speed on the approach to maintain the required spacing between them.

Overall, the Baseline condition was rated with the lowest workload – due to it having the lowest

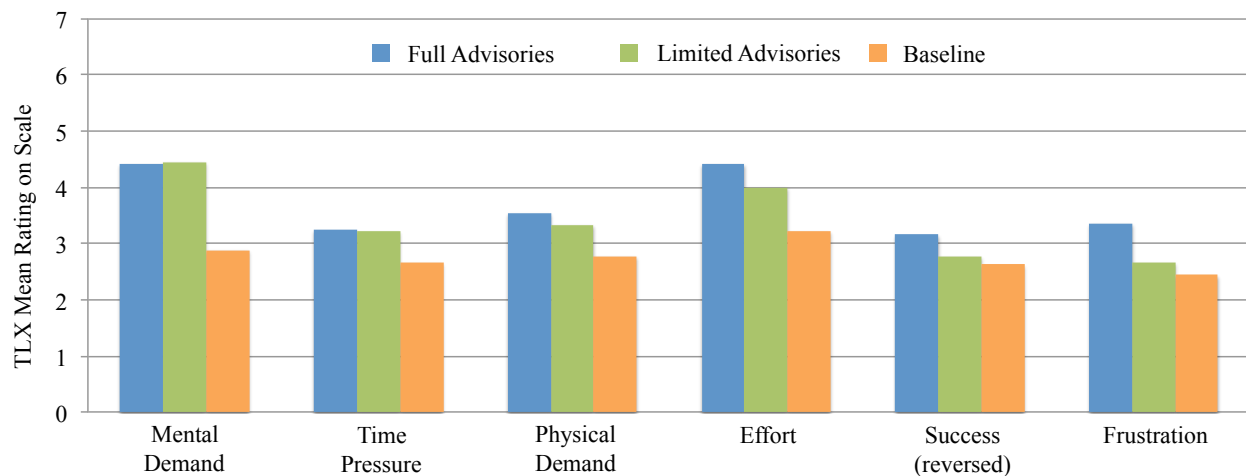


Figure 11. TLX ratings of controllers’ subjective workload

mean ratings on the demand and the affect scales (5 scales excluding success), with means from 2 to 3 (“low” to “somewhat low”). The Full Advisories condition had the highest mean ratings for four of the six sub-scales, while the Limited Advisories condition had the highest mean mental demand ratings. Even the mental demand ratings, which were the highest of the six scales, were manageable at around the mid point of the scale (4 = “comfortable for me” / medium). So, even though workload ratings were higher for conditions with the TAPSS system’s advisories the load was not unmanageable. The workload values were compared for each sub-scale using a Friedman two-way ANOVA: no comparisons were significant, although the mental demand scale approached significance with a p value of .063. In a related question, participants reported they spent a “moderate” amount of time managing the RNP aircraft. Spending an “extensive” amount of time managing the RNP aircraft was only reported once. Participants reported they spent slightly less time managing the RNP aircraft in the Baseline condition.

Using the Advisories

Participants were asked a series of questions to ascertain which TAPSS system’s advisories assisted the controllers in these runs and how much assistance the system’s advisories gave. Participants agreed that having the TAPSS system’s advisories helped to make the RNP procedure “a little easier” under the routine/ordinary conditions of the study ($M=3.52$ out of 5, where 5 was “much easier”). Their average opinions are very similar between the three test

conditions. Looking at the individual ratings, there is little variation in their opinions across the Baseline runs (where they said tools would have either no effect or make the procedures easier to work), but more variation in the Limited Advisories and the Full Advisories runs (where they said the tools could have a range of effects from making the procedure “harder to work” to making it “much easier to work”).

Participants reported they relied most on the trajectory slot markers and speed advisories when available in the Full Advisories conditions, and on the early/late indicators when slot markers and advisories were not available in the Limited Advisories conditions. This is shown in Figure 12. The frequency of use of advisories shown in this figure is from the post-run questionnaires, not the actual use-counts. Although participants did not have access to the system’s advisories in the Baseline condition, they were asked to indicate which TAPSS advisories they would have used if they had had them available. These selections have been included in Figure 12 for comparison, although it must be noted that these frequencies are not based on exactly the same question. Participants were not asked to indicate which of the missing advisories, timeline, slot marker, and speed advisory, they would have used in the Limited Advisories condition. Therefore, the first three sub-scales in Figure 12 do not have values for the Limited Advisories condition.

Early-late indicators share the third rank with the runway assignment when they were available in the

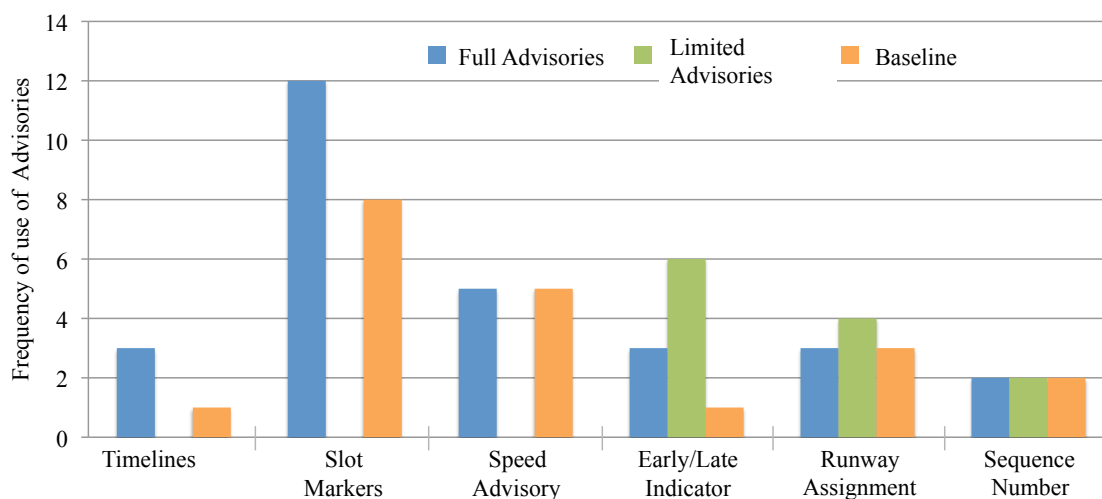


Figure 12. Frequency of TAPSS advisory use

Full Advisories runs but ranked 5th in the Baseline condition when participants were more abstractly indicating tools they would have used. In the Limited Advisories condition, when early/late indicators were the only advisory for gauging schedule performance, they were used twice as often (as in the Full Advisories condition) but still only 50% of the time. Runway sequence number was used less than 25% of the time always, although participants commented in answer to a different question that they used them initially in a run and not later, so this low usage rating may reflect that participants had not used the sequence number recently, i.e., toward the end of a run.

Usefulness of the TAPSS system advisories for the task

A series of four questions asked participants how much the TAPSS system's advisories helped them to complete specific tasks. The Final controller reported that the TAPSS advisories were "quite helpful", on average in aiding their decisions about which aircraft to land next. However, this average obscures that in four of seven cases, the Final controller said the TAPSS advisories were "helpful" and in only one case they said the advisories "didn't help at all."

The Feeder East and West reported the TAPSS advisories were "quite helpful" on average with providing a good flow to the Final, rating the Full Advisories as slightly more helpful on average (M=5.5) than the Limited Advisories (M=5).

Participants reported the TAPSS advisories were "quite helpful" on average (M=4.95) for managing the schedule that the aircraft were on. The Full Advisories were more helpful (M=5.25) than the Limited Advisories (M=4.55) for this particular task. Although the difference between these mean ratings is three-quarters of a scale point, there is no significant difference between them.

Participants reported the TAPSS advisories they had available provided them with a "medium" level of help (on average, M=4.23) with their separation management task. The advisories were slightly more helpful in the Limited Advisories condition (M=4.44) than in the Full Advisories condition (M=4.08). Their answers to this question are in the opposite direction to their answers in the other three questions in this set. In sum, participants thought the suite of Limited Advisories tools were slightly more helpful

for separation management, whereas the suite of Full Advisories tools were rated as more helpful for the tasks of deciding which aircraft to land, providing a good flow, and managing the schedule.

Concluding Remarks

The joint NASA and FAA HITL air traffic simulation presented in this paper extended previous work developing and extensively evaluating the Terminal Area Precision Scheduling and Spacing (TAPSS) system. In this simulation, Performance-Based Navigation arrival operations, including Area Navigation and Required Navigation Performance procedures, were compared and contrasted in three test conditions. They were the Baseline, where none of the TAPSS system's controller decision support advisories were provided, the Limited Advisories, reflecting the existing but dormant capabilities of the current terminal automation equipment with providing a subset of the TAPSS system's advisories, and the Full Advisories, with all of the TAPSS advisories.

Key findings from this simulation are the following. First, the TAPSS system has a potential to enable efficient Performance-Based Navigation arrival operations in the terminal area. Results indicate that with the Full Advisories available in the TAPSS system, a higher percentage of Area Navigation and Required Navigation Performance arrivals stayed within their path when compared to the Baseline during periods of high congestion. Second, the TAPSS system has a potential to reduce controllers' communication task load. Results indicate that the average number of voice commands issued to Area Navigation and Required Navigation Performance arrivals were reduced when using the Full Advisories in the TAPSS system. Third, post-run questionnaires indicated that the study participants found the TAPSS system and its advisories useful. In particular, the participants found the trajectory slot marker, an advanced spatial and temporal delay visual cue, most useful among the available advisories.

Further research is expected to thoroughly investigate the findings from this simulation, with different terminal areas and airports. Incorporation of wind conditions, true and forecast, in future simulations is anticipated.

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